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Vanadium

UNITED STATES DEPARTMENT OF THE INTERIOR

The statistical data in this volume represents the most comprehensive, verified, domestic and international coverage for 1987 at the time the volume went to press. More recent information can be found in the monthly Vanadium Mineral Industry Surveys obtainable from Publications Distribution, Bureau of Mines, Box 18070, Cochrans Mill Road, Pittsburgh, PA 15236.

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UNITED STATES DEPARTMENT OF THE INTERIOR • Manuel J. Lujan, Jr., Secretary

BUREAU OF MINES • T S Ary, Director

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Vanadium

By Henry E. Hilliard[1]

Reported consumption of vanadium (V) increased after more than 2 years of decline. Most of the increase could be attributed to the domestic steel industry, which had a much better year than expected. About 85% of all vanadium was consumed by the steel industry as an alloying agent for steel. Domestic production and shipments of raw steel increased significantly with a corresponding increase in demand and production of vanadium. The increase in demand was met by increased production from fly ash, spent catalysts, and refinery residues. Production from domestic ores declined during this period.

Imports of vanadium raw materials increased due to shortages of domestic ore and petroleum residues. The increase in more expensive imports combined with an increase in the price of aluminum (Al), used in the production of ferrovanadium (FeV) and V-Al masteralloys, resulted in the announcement of price increases by most producers. Overall exports declined despite the lower value of the U.S. dollar but showed signs of improvement in the latter part of the year.

Table 1.—Salient vanadium statistics

(Short tons of contained vanadium unless otherwise specified)

		1983	1984	1985	1986	1987
United States:						
Production:						
Ore and concentrate:						
Recoverable vanadium[1]		2,171	1,617	W	W	W
Value	thousands	$30,675	$24,551	W	W	W
Vanadium oxides recovered from ore[2]		2,433	2,620	W	W	W
Vanadium oxides recovered from petroleum residue[3]		893	1,701	2,695	2,330	2,508
Consumption		3,277	4,761	4,883	4,308	4,653
Exports:						
Ferrovanadium (gross weight)		775	469	454	513	436
Ore and concentrate		59	12	3	86	--
Vanadium pentoxide, anhydride (gross weight)		2,648	3,772	1,527	1,544	1,461
Other compounds (gross weight)		95	305	322	343	479
Imports (general):						
Ferrovanadium (gross weight)		846	1,461	977	747	422
Ores, slags, residues		58	633	303	2,013	2,264
Vanadium pentoxide, anhydride		408	149	63	443	357
World: Production from ores, concentrates, slags		30,924	34,291	[4]33,299	[p] [4]32,530	[e] [4]34,300

[e]Estimated. [p]Preliminary. W Withheld to avoid disclosing company proprietary data.

[1]Recoverable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recovered from ferrophosphorus derived from domestic phosphate rock.

[2]Produced directly from all domestic ores and ferrophosphorus; includes metavanadates.

[3]Includes vanadium recovered from ashes and spent catalysts.

[4]Excludes U.S. production.

Domestic Data Coverage.—Domestic production data for vanadium are developed by the Bureau of Mines from voluntary surveys of U.S. mills and processing facilities. Of the 10 plants and/or mills canvassed in 1987, 9 responded with complete data, representing more than 95% of total production. Production for the one nonrespondent was estimated using reported prior year production levels adjusted by trends in employment and other guidelines. Supplemental data were provided by two power-generating stations. Data on uranium-vanadium mining operations were obtained from an independent survey conducted by the U.S. Department of Energy (DOE). When efforts to obtain response to a Bureau survey fail, it becomes necessary to use estimation techniques to account for the missing data.

Legislation and Government Programs.—The National Defense Stockpile (NDS) goal of 7,700 tons of vanadium contained in vanadium pentoxide (V_2O_5) and 1,000 tons in FeV was in effect throughout 1987. Actual yearend stockpile inventories, reported by the General Services Administration (GSA), contained only 721 tons of vanadium as V_2O_5. In May, a defense authorization bill advanced in the House and the Senate that contained proposals to give Congress more control over NDS goals. The Senate version of the bill would allow the President to retain authority over stockpile goals, but within narrower limits. The President could increase or decrease stockpile goals for materials by up to 10% without congressional approval, but would first have to identify the changes in the annual materials plan. The plan is the President's official advisory to Congress on anticipated NDS acquisitions and disposals. If the President wanted to eliminate or reduce an inventory goal by more than 10%, the change would have to be approved by Congress in the form of legislation. Under provisions of the House bill, which had already passed the Critical Materials Subcommittee, the President would lose all of his independent stockpile goal setting authority. Congress would set the goals by law, and stockpile management would be shifted from GSA to the U.S. Department of Defense. The House and Senate versions of the bill were not complementary and differences were to be worked out in a joint House-Senate Conference Committee.

In a decision of importance to importers of vanadium materials, the Supreme Court ruled that States may tax imported goods sitting in duty-free customs-bonded warehouses if those goods are slated for domestic sale. The decision paved the way for the imposition of State and local taxes on foreign products. U.S. importers sometimes store imported goods in duty-free customs-bonded warehouses when import quotas for a particular product have been filled for the year. During this period, the goods are not subject to local property taxes. Courts have ruled that such goods are part of "the stream of commerce" and should not be taxed by State and local governments. In this case, evidence indicated that the goods in question were scheduled to be used in products sold in the United States, not abroad. The decision could have a considerable impact on storing such goods in the future. About $7 million in local taxes was at issue in this case alone.

In July, the 10th U.S. Court of Appeals in Denver, CO, ruled that DOE must restrict the enrichment of foreign uranium to protect the domestic uranium industry. The case began when domestic uranium-vanadium mining companies challenged DOE's interpretation of a Federal law intended to protect the United States from becoming dependent on foreign uranium. The litigation was based on a section of the Atomic Energy Act that required the Government to ensure the viability of the U.S. uranium industry. DOE first concluded in 1985 and again in 1986 that the industry wasn't viable, but refused to restrict imports, arguing that to do so would exacerbate trade tension with major trade partners such as Canada and would drive nuclear powerplant operators abroad for uranium enrichment. Annual U.S. production slumped from about 44 million pounds of uranium oxide and 15 million pounds of byproduct V_2O_5 in 1980 to less than one-third of that in 1986.[2] Since annual U.S. consumption was about 39 million pounds, utilities and other users reduced stocks or filled needs from Australia, Canada, and elsewhere. Uranium from the Republic of South Africa has already fallen under restrictions owing to anti-apartheid sanctions. In 1986, imports of South African uranium surged 300% to more than 13 million pounds. Almost 60% of the deliveries took place in December 1986, the last month before the embargo took effect.

DOMESTIC PRODUCTION

Production of V_2O_5 and shipments of finished products saw slight increases in 1987 with most of the increases coming in the fourth quarter. Pentoxide production was more than 6,000 tons compared with less than 5,000 tons in 1986. Production of V_2O_5 was aided by an unexpected good year for the steel industry, where raw steel production was up more than 8%. V_2O_5 is the principal starting material for the manufacture of alloys, chemicals, catalysts, and other vanadium compounds.

Recoverable production, which represents receipts of domestic ore and vanadium-bearing ferrophosphorus slag, continued the decline that began in 1983. Production from ores was closely tied to the uranium industry, which had fallen on hard times in the 1980's because of reduced demand, imports, and excess capacity, resulting in a sharp decline in the price of uranium oxide (U_3O_8). The outlook for the moribund uranium-vanadium mining and milling industry showed signs of improvement in late 1987, particularly after a favorable decision by the 10th U.S. Circuit Court of Appeals restricted the use of DOE enrichment facilities to domestic material. It would not, however, affect enrichment of foreign uranium for reexport, nor the ability of domestic utilities to have their uranium enriched outside the United States. Vanadium production lost from domestic ores was partially offset by increased production from low-cost petroleum residues, utility ash, and spent catalysts.

Shieldalloy Corp., Newfield, NJ, bought Foote Mineral Corp.'s ferrovanadium plant in Cambridge, OH, for $6.8 million in June. Shieldalloy is a producer of ferroalloys, tantalum, aluminum master alloys, and chromium. In December, the parent company of Shieldalloy, the Metallurg Group, announced plans to merge Shieldalloy with Metallurg Alloy Corp., effective January 1, 1988. The new company, Shieldalloy Metallurgical Corp., will maintain its headquarters in New York, NY. Shortly after announcing the merger, Shieldalloy and Affiliated Metals and Minerals Inc., Pittsburgh, PA, signed a letter of intent to develop a joint venture to produce V_2O_5 from a fly ash previously thought to be too low in vanadium content for economical processing. The processing plant was to be in New Castle, PA, where Affiliated operated an FeV unit and had some of the equipment already in place for producing V_2O_5 from vanadium-bearing slags. All output from the plant will be consumed internally in the production of FeV.

The Umetco Minerals Div. of Union Carbide Corp. reopened the LaSalle uranium mine in Utah and hired several miners to fulfill delivery contracts rather than continue to purchase ore as in the past. Ore from the mine was used to supply the White Mesa mill at Blanding, UT. The mill resumed operation in late 1985 after being closed for several months. The mill, with a design capacity of 2,000 tons of ore per day, produced 4.8 million pounds of uranium oxide and 2.8 million pounds of V_2O_5 in 1986.[3] Meanwhile, Atlas Corp. announced a restructuring of its operations to focus on its core business of mining precious metals. The company closed its uranium operations because of the continuing depressed state of the uranium industry. Atlas' uranium-vanadium mill at Moab, UT, had been closed since 1985.

Strategic Minerals Corp. (Stratcor), Danbury, CT, began producing Nitrovan in the United States for the first time. Nitrovan is a nitrogen derivative of vanadium containing 5% to 10% nitrogen. The company previously produced the additive for steel only at its plant in Brits, Republic of South Africa. A new facility was built at an existing vanadium plant in Niagara Falls, NY. Stratcor installed a new furnace, mixing facilities, and other equipment at a cost estimated at about $9 million.

Table 2.—Mine production and recoverable vanadium of domestic origin produced in the United States

(Short tons of contained vanadium)

Year	Mine production[1]	Recoverable vanadium[2]
1983	W	2,171
1984	W	1,617
1985	W	W
1986	W	W
1987	W	W

W Withheld to avoid disclosing company proprietary data.

[1]Measured by receipts of uranium and vanadium ores and concentrates at mills, vanadium content.

[2]Recoverable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recovered from ferrophosphorus derived from domestic phosphate rock.

Table 3.—U.S. production of vanadium oxides[1]

(Short tons)

Year	Gross weight	Oxide content[2]
1983	4,590	4,344
1984	4,688	4,678
1985	W	W
1986	W	W
1987	W	W

W Withheld to avoid disclosing company proprietary data.
[1]Produced directly from all domestic ores and ferrophosphorus; includes metavanadates.
[2]Expressed as equivalent V_2O_5.

CONSUMPTION, USES, AND STOCKS

Reported consumption of vanadium compounds in 1987 was 4,653 tons of contained vanadium. The largest consumers were producers of high-strength low-alloy steels, followed by carbon steel and full alloy steels.

One of the most important uses of vanadium is as an alloying element by the steel industry. The addition of 1% to 5% vanadium-to-steel produces grain refinement and increases the hardenability. Vanadium is a strong carbide former, which causes carbide particles to form in the steel, thus restricting the grain boundaries during heat treatment. This produces a fine grain that exhibits greater toughness and impact resistance than a course-grained steel and is more resistant to cracking during quenching. The carbide dispersion also confers wear resistance, weldability, and good high-temperature strength. Vanadium steels are used in dies and taps because of their wear resistance. They also are used as construction steels in light and heavy sections, for heavy iron and steel castings, forged parts, automobile parts, springs, and ball bearings. Vanadium is an important component of ferrous alloys used in jet aircraft engines and turbine blades, where high-temperature creep resistance is required.

The principal application of vanadium in nonferrous alloys was in the titanium 6Al-4V alloy, which is irreplaceable in supersonic aircraft, where strength-to-weight ratio is a primary consideration. Vanadium imparts high-temperature strength to titanium, a property essential in high-performance jet engines, high-speed air frames, and rocket motor cases. Vanadium foil can be used as bonding material in the cladding of titanium to steel. Vanadium can be used in copper-base alloy production to control gas content and microstructure. Small amounts of vanadium are added to aluminum alloys used in the manufacture of pistons for internal combustion engines. The vanadium enhances the alloy's strength and reduces its coefficient of thermal expansion. Vanadium is a component in several permanent-magnet alloys containing cobalt, iron, and nickel. The most common of these alloys contains 2% to 13% vanadium. Vanadium compounds are also used as catalysts in certain chemical and petrochemical reactions.

Reported consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals totaled 2,057 tons of contained vanadium at yearend 1987 compared with 1,842 tons at yearend 1986. Combined producers' and consumers' stocks represented a 3-month supply at the current rate of consumption.

Table 4.—Producers of vanadium alloys or metal in the United States in 1987

Producer	Plant location	Products[1]
Affiliated Metals and Minerals Inc	New Castle, PA	FeV.
KB Alloys Inc	Henderson, KY	VAl, ZrVAl.
Do	Wenatchee, WA	Do.
Reading Alloys Inc	Robesonia, PA	FeV, VAl, V.
Shieldalloy Metallurgical Corp	Newfield, NJ	FeV, Ferovan.[2]
Strategic Minerals Corp	Niagara Falls, NY	FeV, VAl, Nitrovan,[2] Carvan.[2]
Teledyne Wah Chang Albany	Albany, OR	V, VAl.

[1]FeV, ferrovanadium; V, vanadium metal; VAl, vanadium aluminum; ZrVAl, zirconium vanadium aluminum.
[2]Registered trademarks for patented products.

Table 5.—U.S. consumption and consumer stocks of vanadium materials, by type

(Short tons of contained vanadium)

Type	1986		1987	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovanadium[1]	3,617	252	3,925	322
Oxide	11	W	17	10
Ammonium metavanadate	W	W	W	W
Other[2]	680	62	711	40
Total	4,308	314	4,653	372

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes other vanadium-iron-carbon alloys as well as vanadium oxides added directly to steel.
[2]Consists principally of vanadium-aluminum alloy, plus relatively small quantities of other vanadium alloys and vanadium metal.

Table 6.—U.S. consumption of vanadium in 1987, by end use

(Short tons of contained vanadium)

End use	Quantity
Steel:	
Carbon	1,197
Stainless and heat-resisting	65
Full alloy	816
High-strength low-alloy	1,336
Tool	465
Unspecified	--
Total	3,879
Cast irons	25
Superalloys	10
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	W
Welding and alloy hard-facing rods and materials	7
Nonferrous alloys	684
Other alloys[1]	W
Chemicals and ceramics:	
Catalysts	12
Other[2]	W
Miscellaneous and unspecified	36
Grand total	4,653

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes magnetic alloys.
[2]Includes pigments.

PRICES

The Metals Week price quotation for domestic 98% fused V_2O_5 (metallurgical-grade) at the beginning of 1987 was $3.65 per pound V_2O_5 content, f.o.b. mill. Domestic FeV producers, Stratcor of Danbury, CT, and Shieldalloy Metallurgical Corp. at Newfield, NJ, raised the prices of their FeV by 25 cents and 30 cents per pound, respectively. Stratcor's price for 80% FeV was raised to $6.75 per pound of contained vanadium. Stratcor's new prices for its patented products, Vanox and Nitrovan, were raised to $5.75 and $7.00 per pound, respectively. Shieldalloy increased the price of its standard 60% FeV and 42% Ferovan to $6.60 per pound. Shieldalloy also raised the price of its ammonium vanadate by 30 cents to $5.00 per pound. Both companies cited rising costs for raw materials and aluminum as the major cause of the price increases. Meanwhile, Reading Alloys, Robesonia, PA, increased the prices of its aluminum master alloys, effective at the end of the fourth quarter. The new prices were $10.35 per pound for the 65% vanadium alloy and $11.85 per pound for the 85% alloy.

The round of price increases began after Highveld Steel and Vanadium Corp. Ltd. of South Africa successfully raised its fourth quarter prices for V_2O_5 by 10% to $2.95 per pound. Also, better-than-expected steel production in the United States increased the demand for vanadium as an alloying agent, which tended to support higher prices.

FOREIGN TRADE

Exports of vanadium products were essentially unchanged from those of 1986, after declining each year since 1984. Canada, the Federal Republic of Germany, Japan, and Mexico were the largest importers of U.S. vanadium products. Other major importers were Taiwan and the Republic of Korea. With the exception of Canada and the Republic of Korea, these countries imported V_2O_5 almost exclusively. Exports of V_2O_5 and catalysts containing V_2O_5 totaled 1,461 tons, slightly less than the 1,500 tons exported in 1986 and considerably less than the 3,712 tons exported in 1984. The average declared value of V_2O_5 exports was about $3.00 per pound; for FeV exports, the average value was $4.68 per pound of contained vanadium. Imports for consumption of major vanadium compounds declined after increasing in 1984 and 1985, while imports of vanadium raw materials increased. Imports for consumption of FeV totaled 422 tons gross weight, down from 747 tons in 1986. The FeV averaged about 81% vanadium with a mean customs value of $5.53 per pound of contained vanadium. Austria was the largest exporter of FeV to the United States, followed by Canada, the Federal Republic of Germany, and the Republic of South Africa. Pentoxide imports totaled 229 tons V content with a mean customs value of $4.83 per pound. The Republic of South Africa was by far the leading source of V_2O_5 imports, with more than 207 tons. Imports of vanadium contained in ores, slags, and residues totaled 2,264 tons V content, a 12% increase over 1986 imports. About 41% of these imports were in the form of vanadiferous iron slags from Highveld's Witbank steelworks in the Republic of South Africa. The remaining 60% consisted of an assortment of petroleum residues, spent catalysts, and utility ash from, in order of decreasing tonnages, Kuwait, Mexico, Venezuela, the Federal Republic of Germany, Canada, and 14 other countries.

Table 7.—U.S. exports of vanadium in 1987, by country

(Thousand pounds and thousand dollars)

Country	Ferrovanadium (gross weight)		Vanadium ore and concentrate (vanadium content)		Vanadium compounds (gross weight)			
					Pentoxide (anhydride)[1]		Other[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	--	--	--	--	5	34	10	15
Australia	--	--	--	--	98	142	--	--
Bangladesh	--	--	--	--	18	27	--	--
Belgium-Luxembourg	--	--	--	--	35	38	22	99
Brazil	--	--	--	--	350	837	557	585
Canada	393	1,964	--	--	482	669	134	353
Chile	--	--	--	--	(3)	6	2	3
Colombia	--	--	--	--	4	6	--	--
Denmark	--	--	--	--	49	59	--	--
Finland	--	--	--	--	--	--	52	62
France	--	--	--	--	--	--	5	32
Germany, Federal Republic of	--	--	--	--	21	102	1	5
Hungary	--	--	--	--	--	--	41	49
India	15	65	--	--	--	--	--	--
Indonesia	--	--	--	--	9	18	--	--
Italy	--	--	--	--	2	15	--	--
Japan	--	--	--	--	385	902	42	77
Korea, Republic of	172	853	--	--	253	352	--	--
Malaysia	2	8	--	--	7	10	(3)	2
Mexico	68	358	--	--	643	1,502	43	135
Netherlands	--	--	--	--	--	--	50	80
Norway	--	--	--	--	48	87	--	--
Pakistan	--	--	--	--	17	35	--	--
Peru	--	--	--	--	3	3	--	--
Philippines	--	--	--	--	62	93	--	--
Singapore	--	--	--	--	74	86	--	--
Switzerland	--	--	--	--	42	83	--	--
Taiwan	--	--	--	--	267	367	--	--
Thailand	--	--	--	--	29	40	--	--
Uruguay	--	--	--	--	11	18	--	--
Venezuela	222	833	--	--	4	34	--	--
Zimbabwe	--	--	--	--	3	3	--	--
Total[4]	872	4,081	--	--	2,922	5,566	958	1,498

[1]May include catalysts containing vanadium pentoxide.
[2]Excludes vanadates.
[3]Less than 1/2 unit.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Table 8.—U.S. imports of ferrovanadium, by country

(Thousand pounds and thousand dollars)

Country	1986			1987		
	Gross weight	Vanadium content	Value	Gross weight	Vanadium content	Value
General imports:						
Austria	311	255	1,459	449	367	2,045
Belgium-Luxembourg	37	30	139	--	--	--
Canada	53...	430	2,495	275	228	1,202
China	22	18	105	--	--	--
Germany, Federal Republic of	249	194	1,006	86	62	392
South Africa, Republic of	303	248	1,135	34	28	138
United Kingdom	40	32	188	--	--	--
Total[1]	1,494	1,207	6,527	843	685	3,777
Imports for consumption:						
Austria	311	255	1,459	449	367	2,045
Belgium-Luxembourg	37	30	139	--	--	--
Canada	532	430	2,495	275	228	1,202
Germany, Federal Republic of	249	194	1,006	86	62	392
South Africa, Republic of	303	248	1,135	34	28	138
United Kingdom	40	32	188	--	--	--
Total[1]	1,472	1,189	6,423	843	685	3,777

[1]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Table 9.—U.S. imports of vanadium pentoxide (anhydride), by country

Country	1986			1987		
	Gross weight (pounds)	Vanadium content (pounds)	Value	Gross weight (pounds)	Vanadium content (pounds)	Value
General imports:						
Belgium-Luxembourg	27,479	20,996	$89,061			
China	435,398	243,910	1,042,694	534,979	290,939	$1,349,202
France	2,863	1,604	16,172			
Germany, Federal Republic of	22,430	12,565	98,310	1,655	391	6,258
Japan				18	10	1,301
South Africa, Republic of	1,064,566	607,574	2,547,157	740,254	414,690	2,012,907
Total[1]	1,562,736	886,649	3,793,394	1,275,706	714,651	3,369,568
Imports for consumption:						
Belgium-Luxembourg	27,479	20,996	89,061			
China	435,398	243,910	1,042,694	74,957	41,991	189,787
France	2,863	1,604	16,172			
Germany, Federal Republic of	22,430	12,565	98,310	1,655	391	6,258
Japan				18	10	1,301
South Africa, Republic of	972,132	544,589	2,317,482	740,254	414,690	2,012,907
Total[1]	1,470,302	823,663	3,563,719	816,284	457,282	2,210,153

[1]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

WORLD REVIEW

Australia.—According to a report released by the Australian Bureau of Mineral Resources, Australia has almost 10 million tons of demonstrated "paramarginal" vanadium resources, in addition to 10,000 tons of demonstrated economic vanadium deposits. About 85% of total identified resources is in oil shale deposits at Julia Creek, Queensland, whose development depends on oil economics. Australia also has substantial resources of vanadium in titaniferous magnetite. Possible development of those deposits, however, most likely would be driven by the titanium market and would require development of economic techniques to recover metal values from the magnetite ores. The magnetites could be used to produce pig iron with titanium- and vanadium-rich slags as a byproduct. Until now, little or no investigative work had been done on the mineralogy of these ores or on their amenability to metallurgical concentration and recovery techniques.

Brazil.—Finland's Rautaruukki began negotiations for the sale of a vanadium plant and process technology to Odobrech of Brazil. Plant capacity was scheduled to be 4,900 tons V_2O_5 per year; 1,700 tons of production will be exported with the remainder converted to FeV for internal consumption. The plant will use feed from ore deposits in Maracus and Campo Alegre de Lordes. The deposits average 1.3% V_2O_5. Production, the first ever in Brazil, is expected to begin in 1990. In 1986, Brazil imported most of its V_2O_5 from the Federal Republic of Germany and the United States.

China.—The Bank of China arranged a $210 million loan for the expansion of the iron and steel complex at Panzhihua, Sichuan. The transaction involved 24 banks in 12 countries, including the First National Bank of Chicago. The loan was part of $810 million allocated by the Government to double annual crude steel output at Panzhihua to 3 million tons. Although China is the world's fourth largest steel producer, the average per capita output is less than 110 pounds, compared with the world average of 353 pounds. The syndicated loan will be used to finance the importation of key equipment and instruments, and the remainder will be used for the construction of a blast furnace, a continuous-casting plant, a cold-rolling mill, and a hot-rolling mill.

Ore used by the steel complex was a titaniferous magnetite with a high vanadium content. The Chinese planned to boost production of titanium to 50,000 tons per year and V_2O_5 to 2,000 tons per year. The Panzhihua Mine, with reserves of 30 million tons and 80% of China's vanadium slag

production, was slated to produce 2,000 tons of V_2O_5 per year. However, the Government failed to find a foreign partner to establish a joint venture with an aim to improve the present yields.

China produced V_2O_5 in six locations, four of which could also produce ferrovanadium. The Panzhihua Iron and Steel Co. plant in Sichuan is a steel plant with an annual production of 70,000 tons of vanadium slag (about 12% V_2O_5). It used titaniferous magnetite ore delivered from a nearby mine to produce pig iron. Vanadium-bearing slags from Panzhihua were shipped to the country's vanadium plants for processing into vanadium pentoxide.

The Emei ferroalloy plant in Sichuan is equipped with a rotary kiln with the capacity to produce 1,000 tons of V_2O_5 per year. Export sales were made through the Sichuan branch of China Metallurgical Import and Export Corp. The Chengde plant in Hebei is equipped with a rotary kiln with the capacity to produce 1,500 tons of V_2O_5 per year and also has the technology to produce ferrovanadium. The Shanghai metallurgical plant No. 2 has two 40-meter rotary kilns with the capacity to produce 2,300 tons of V_2O_5 per year. The plant received vanadium slags from the ironworks in Ma'anshan. The Jinzhou ferroalloy plant in Liaoning, with three 40-meter kilns, is capable of producing 6,000 tons of V_2O_5 per year and 4,000 tons of FeV per year. The plant, equipped with a furnace rated at 4,000 tons of FeV capacity per year, also produced chromium metal and ferrotitanium. The Nanjing ferroalloy plant in Jiangsu has the capacity to produce 1,000 tons of V_2O_5 per year. It currently produces about 350 tons of V_2O_5 and about 200 tons of FeV annually, primarily from oil shale.

South Africa, Republic of.—The first stage of the Kennedy's Vale vanadium project, under construction near Steelpoort in eastern Transvaal for Vansa Vanadium S.A. Ltd., was completed in August, and the plant was scheduled for commissioning in June 1988. Capital cost of the plant increased to about $12.6 million compared with earlier estimates of $7.2 million. The first sales of V_2O_5 were expected to take place in July 1988. The plant was to produce 3,300 tons of V_2O_5 and an unspecified amount of ammonium metavanadate for sale in Japan, South America, and the European Community. Initially, sales are expected to be relatively small with little impact on world markets. However, Vansa plans a rapid and aggressive buildup of sales, with vanadium providing the majority of its earnings by 1989.

Vanadium was produced by three companies. The largest of the three, Highveld Steel and Vanadium Corp., operated the Mapochs Mine at Roossenekal in eastern Transvaal. Highveld produced vanadium slags and pentoxide at two plants situated near Witbank. The Vantra Div. extracted V_2O_5 by the roast-leach process; Highveld Steel ironworks smelts the ore in electric furnaces after prereduction in rotary kilns. The other two companies, Transvaal Alloys Pty. Ltd. and Vametco Minerals Co., extracted vanadium by a similar roast-leach process and produced V_2O_5 and other vanadium compounds. Ore was mined from nearby surface deposits.

South African vanadium producers have not revealed production and commercial information since 1985 because of the growing pressure of anti-apartheid sanctions against the country. The last published figures available from the Government-operated Minerals Bureau put vanadium production in 1985 at about 13,000 tons, 40% of world output and 71% of Western World production. Estimates for 1987 varied from a low of 15,700 tons to a high of more than 18,000 tons.

Venezuela.—In December 1987, Venezuela ranked second as an oil exporter to the United States, averaging about 850,000 barrels per day. Venezuelan oil may contain up to 1,500 parts per million of vanadium, which translates to more than 80,000 pounds per day of V_2O_5 entering the United States.[6] In its push to open new markets for its oil, Venezuela had been buying interest in petroleum refineries, particularly in the United States. Among recent investments were 50% interest in refineries at Lake Charles, LA, and Corpus Christi, TX. Through additional joint ventures in the United States, Petróleos de Venezuela S.A. (PDVSA) expected to expand sales by 700,000 barrels of crude per day.

U.S. geological teams visited Venezuela to confirm the country's sharp upward revisions in its estimates of proven oil reserves. Venezuela's recent upgrading more than doubled its own estimates of proven reserves to 55 billion barrels, about twice those of the United States. In addition, PDVSA counted 267 billion barrels of proven reserves of lower quality, extra heavy crude in its Orinoco Oil Belt. Proven reserves are generally defined as those that can be produced with current technology at today's prices.

Table 10.—Vanadium: World production, by country[1]

(Short tons of contained vanadium)

Country	1983	1984	1985	1986[p]	1987[e]
Production from ores, concentrates, slag:[2]					
China (in vanadiferous slag product)[e]	5,000	5,000	5,000	5,000	5,000
Finland (in vanadium pentoxide product)	3,516	3,376	2,350	--	--
South Africa, Republic of:[3]					
Content of pentoxide and vanadate products[e]	4,117	6,653	6,507	[e]9,350	6,600
Content of vanadiferous slag product[e, 4]	5,629	7,165	8,912	10,580	12,100
Total	9,747	13,798	15,449	16,930	18,700
U.S.S.R.[e]	10,500	10,500	10,500	10,600	10,600
United States (recoverable vanadium)	2,171	1,617	W	W	W
Total	30,924	34,291	[e]33,299	[e]32,530	[e]34,300
Production from petroleum residues, ashes, spent catalysts:[5]					
Japan (in vanadium pentoxide product)	778	[e]770	[e]840	929	925
United States (in vanadium pentoxide and ferrovanadium products)	893	1,701	2,695	2,330	[e]2,508
Total	1,671	2,471	3,535	3,259	3,433
Grand total	32,595	36,762	36,834	35,789	37,733

[e]Estimated. [p]Preliminary. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]In addition to the countries listed, vanadium is also recovered from petroleum residues in the Federal Republic of Germany, the U.S.S.R., and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through July 15, 1988.

[2]Production in this section is credited to the country that was the origin of the vanadiferous raw material.

[3]Includes production for Bophuthatswana.

[4]Reported figure.

[5]Data on vanadium content of vanadium slag are estimated on the basis of a reported tonnage of vanadium-bearing slag (gross weight) multiplied by an assumed grade of 14.1% vanadium.

[6]Excludes U.S. production.

[7]Production in this section is credited to the country where the vanadiferous product is extracted; available information is inadequate to permit crediting this output back to the country of origin of the vanadiferous raw material.

TECHNOLOGY

Several occurrences of placer mineral deposits have been identified in Alaska and are being investigated by the Bureau of Mines as part of its program to inventory the State's vast but little-known mineral wealth.[8] Although the deposits are not likely to be economic at current metal prices, more than 40 million tons of mineralized materials have been inferred, and it is likely that additional tonnages could be found with more intensive exploration. Geochemically anomalous values of vanadium and several other metals, including rare earths, were identified in some of the placer concentrates taken in drainages of the White Mountain study area. The presence of anomalous values probably indicates the presence of lode rather than placer mineralization.

Most vanadium is recovered as a byproduct of other processes such as the leaching of carnotite uranium ores. Vanadium recovery from leach solutions is usually done by dialkylphosphoric acid (DAPEX) or by amine (AMEX) solvent extraction processes. The AMEX process requires the oxidation of vanadium to the pentavalent state prior to solvent extraction. Sodium chlorate and, to a lesser extent, hydrogen-peroxide-oxygen systems are used as oxidants. Sodium chlorate has the disadvantage of being slow and requiring high operating temperatures. Hydrogen peroxide is an effective oxidant but may result in waste owing to decomposition and reductive side reactions. Comparative oxidation tests using two actual uranium mill raffinates showed that the use of Caro's acid eliminated these problems.[9] A four-stage countercurrent extraction performed on the raffinates revealed that extraction efficiency and the extraction coefficient were higher when Caro's acid was used as opposed to hydrogen peroxide.

Researchers at the University of New South Wales in Australia demonstrated a rechargeable storage battery employing electrically charged vanadium solutions instead of the conventionally charged plates of lead-acid batteries.[7] The battery is based on National Aeronautics and Space Administration redox flow cell research and uses two vanadium solutions pumped separately through adjacent half cells. Electricity is produced by the exchange of electrons between the solutions. The researchers ex-

pected to have a prototype 25-kilowatt-hour battery ready for production in 1989. An international marketing agreement was signed between the university's commercial arm, Unisearch Ltd., and Agnew Clough Ltd. of Western Australia. In related research, a number of vanadium oxides were studied with special regard to their application as the active component in rechargeable lithium cells.[8] Substances with so-called open crystal structures are used as electrochemically active materials for insoluble positive electrodes in secondary lithium cells. The lattices of these substances have cavities that act as open, freely passable channels for lithium ions. Vanadium oxides are of special interest for this particular application because of their comparatively low equivalent weight.

Extensive testing of commercial fluid cracking catalysts (FCC) showed that, when all metals are removed by demineralizing the catalyst, the catalyst is effectively reactivated. Because vanadium is the primary metal associated with catalytic activity, it is important to understand the effect on catalytic activity when only the vanadium is removed. To isolate the vanadium effect on catalysts, researchers at ChemCat Corp. performed tests on various nonzeolitic amorphous catalysts, zeolitic rare-earths (REY) catalysts, and zeolitic ultrastable Y (USY) catalysts, where vanadium was the only metal removed.[9] Results were compared with reactivation by the Demet process, which effectively removes the vanadium as well as the iron, nickel, and sodium. Vanadium was removed from samples of FCC catalyst obtained from two different refineries, and, in each case, their catalytic activity was selectively improved.

An Israeli botanist identified a microscopic fungus that acts as a superabsorbent sponge, soaking up large amounts of the metals that are often found in the wastewater from mining and manufacturing processes. The fungus can extract such heavy metals as mercury, nickel, vanadium, and uranium.[10] Apparently, the fungus works more quickly, can be grown more cheaply, and can be reused more often than other microorganisms under study. When effluent passes through a filter impregnated with the fungus, the fungus separates metals from the water after only a brief contact time. After the fungus is sated with the metals, it can easily be removed from the filter, the metals extracted, and the fungus reused.

A contract for continued research into the use of powder metal aluminum alloys for use at temperatures as high as 600° F to replace titanium aircraft components was awarded to Lockheed Aeronautical Systems Co., Burbank, CA.[11] The new alloys may find applications in the Advanced Tactical Fighter (ATF) under development by the U.S. Air Force. The alloys being tested include FES 0812 and FES 1212 from the research and development centers of Allied-Signal Corp., Morristown, NJ. The alloys are based on an aluminum-iron-vanadium-silicon mix. According to Allied, the alloys can be used at temperatures as high as 800° F.[12]

Most of the technology used industrially to extract vanadium from refinery residues, oil-fired boiler slags, and fly ash include roasting the material at high temperature followed by leaching with aqueous solvents. Japanese researchers developed a process for the extraction of metal values without roasting using the technique of direct leaching with subsequent solvent extraction.[13] Hydrochloric acid leaching showed the best extraction capability for vanadium and other metals. Sodium hydroxide leaching showed the highest selectivity for vanadium. A combination of the two leaching methods hastened the recovery and separation of metals.

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